

WHAT IS CLAIMED IS:

1. A system for efficiently performing a pattern matching procedure, comprising:

5 an enrollment manager that performs an image conversion procedure for converting an initial reference image into a reference template, said image conversion procedure including a binarization procedure or a symmetrical reduction procedure; and

10 a verification manager that converts an initial test image into a transformed test image, said verification manager then combining said reference template and said transformed test image into a correlation image, said verification manager analyzing matching characteristics of said correlation image to
15 determine whether said initial test image matches said initial reference image.

2. The system of claim 1 wherein an image capture device provides said initial reference image for creating said reference template, said pattern
20 matching procedure utilizing said reference template to verify a user identity of a system user corresponding to said initial test image.

3. The system of claim 1 wherein said initial reference image and said initial test image each includes image data that represents a user fingerprint
25 or a user face of a corresponding system user.

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4. The system of claim 1 wherein said enrollment manager performs a first binarization step to create initial binarization values for said binarization procedure by substituting a decimal value of "1" for all complex coefficients from said initial reference image that are greater than or equal to zero, said enrollment manager also substituting a decimal value of "-1" for all of said complex coefficients that are less than zero, said initial binarization values then being utilized for any further calculations during said pattern matching procedure.

5. The system of claim 4 wherein said enrollment manager performs a second binarization step to create stored binarization values for said binarization procedure by substituting a binary value of "1" for all of said complex coefficients from said initial binarization values that are equal to "-1", and by also substituting a binary value of "0" for all of said complex coefficients from said initial binarization values that are equal to "1", said complex coefficients thus each being expressed with a single binary bit, said stored binarization values subsequently being converted into said initial binarization values for performing any required mathematical calculations.

6. The system of claim 1 wherein said initial reference image is converted by a Fast Fourier Transform procedure into an FFT reference image that exhibits symmetrical characteristics across individual complex pixel values, said enrollment manager performing said symmetrical reduction procedure on said FFT reference image to produce a reduced reference image to conserve processing requirements and memory requirements, said FFT reference image being divided during said symmetrical reduction procedure into a reduced portion that is stored as said reference template, and a discarded portion that is not utilized during said pattern matching procedure.

7. The system of claim 1 wherein said verification manager creates said correlation image by performing a multiplication procedure that multiplies corresponding pixel values from said reference template and said transformed test image to produce correlation pixel values for said correlation image, said correlation pixel values being obtained from a multiplication lookup table to conserve system resources such as processing requirements and memory requirements.

8. The system of claim 7 wherein said multiplication lookup table is implemented with initial binarization values from said binarization procedure, each complex value from said reference template and said transformed test image being expressed with one of only four complex numbers, said four complex numbers being " $1 + j$ ", " $1 - j$ ", " $-1 + j$ ", and " $-1 - j$ ", said multiplication lookup table including a vertical reference-pixel index column having a first reference pixel value ($1 + j$), a second reference pixel value ($1 - j$), a third reference pixel value ($-1 + j$), and a fourth reference pixel value ($-1 - j$), said multiplication lookup table also including a horizontal test-pixel index row having a first test pixel value ($1 + j$), a second test pixel value ($1 - j$), a third test pixel value ($-1 + j$), and a fourth test pixel value ($-1 - j$).

9. The system of claim 1 wherein said enrollment manager converts said initial reference image into an FFT reference image by performing a Fast Fourier Transform procedure upon said initial reference image.

10. The system of claim 9 wherein said enrollment manager performs a two-step binarization procedure upon said FFT reference image to produce a binarized reference image that is stored with a single binary bit representing each complex pixel value coefficient.

11. The system of claim 1 wherein said enrollment manager performs a symmetrical reduction procedure upon said binarized reference image to produce a reduced reference image which said enrollment manager stores as said reference template.

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12. The system of claim 1 wherein said verification manager converts said initial test image into an FFT test image by performing a Fast Fourier Transform procedure upon said initial test image.

10 13. The system of claim 12 wherein said verification manager performs a two-step binarization procedure upon said FFT test image to produce a binarized test image that is stored with a single binary bit representing each complex pixel value coefficient.

15 14. The system of claim 13 wherein said verification manager performs a symmetrical reduction procedure upon said FFT test image to produce and store a reduced test image.

15. The system of claim 14 wherein said verification manager performs a
20 complex conjugation procedure upon said reference template to produce a conjugated reference image, said complex conjugation procedure converting each pixel value from said reference template into a corresponding complex conjugate value by inverting an arithmetic operation that connects real and imaginary portions of complex values for said each pixel value from said
25 reference template.

16. The system of claim 15 wherein said verification manager performs a multiplication procedure with said conjugated reference image and said reduced test image to produce a reduced correlation image.

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17. The system of claim 16 wherein said verification manager performs said multiplication procedure by referencing a multiplication lookup table to index pixel values from said conjugated reference image and said reduced test image to produce corresponding correlation pixel values for said reduced correlation image.

18. The system of claim 16 wherein said verification manager performs a symmetrical regeneration procedure upon said reduced correlation image to produce a full FFT correlation image.

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19. The system of claim 18 wherein said verification manager performs an inverse FFT procedure upon said full FFT correlation image to generate a complex correlation image, said verification manager discarding imaginary values from each pixel value of said complex correlation image to produce a real correlation image, said verification manager then performing an FFT shift procedure to generate a correlation graph that represents pixels from said real correlation image.

20. The system of claim 19 wherein said verification manager computes a peak side-lobe ratio from said correlation graph for comparing with a pre-determined correlation threshold to determine whether said initial test image matches said initial reference image, said peak side-lobe ratio being expressed by a formula:

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$$\text{PSR} = (\text{Peak Value} - \text{Mean Value}) / \text{STD}$$

where said PSR is said peak side-lobe ratio, said Peak Value is a correlation image pixel with a greatest magnitude, said Mean Value is an arithmetical mean value of correlation image pixels in a pre-defined side-lobe area surrounding said Peak Value, and said STD is a standard deviation of said correlation image pixels in said pre-defined side-lobe area.

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21. A method for efficiently performing a pattern matching procedure, comprising:

performing an image conversion procedure with an enrollment manager to convert an initial reference image into a reference template, said image conversion procedure including a binarization procedure or a symmetrical reduction procedure;

converting an initial test image into a transformed test image with a verification manager;

combining said reference template and said transformed test image into a correlation image with said verification manager; and

analyzing matching characteristics of said correlation image with said verification manager to determine whether said initial test image matches said initial reference image.

22. The method of claim 21 wherein an image capture device provides said initial reference image for creating said reference template, said pattern matching procedure utilizing said reference template to verify a user identity of a system user corresponding to said initial test image.

23. The method of claim 21 wherein said initial reference image and said initial test image each includes image data that represents a user fingerprint or a user face of a corresponding system user.

24. The method of claim 21 wherein said enrollment manager performs a first binarization step to create initial binarization values for said binarization procedure by substituting a decimal value of "1" for all complex coefficients from said initial reference image that are greater than or equal to zero, said enrollment manager also substituting a decimal value of "-1" for all of said complex coefficients that are less than zero, said initial binarization values then being utilized for any further calculations during said pattern matching procedure.

25. The method of claim 24 wherein said enrollment manager performs a second binarization step to create stored binarization values for said binarization procedure by substituting a binary value of "1" for all of said complex coefficients from said initial binarization values that are equal to
5 "-1", and by also substituting a binary value of "0" for all of said complex coefficients from said initial binarization values that are equal to "1", said complex coefficients thus each being expressed with a single binary bit, said stored binarization values subsequently being converted into said initial binarization values for performing any required mathematical calculations.

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26. The method of claim 21 wherein said initial reference image is converted by a Fast Fourier Transform procedure into an FFT reference image that exhibits symmetrical characteristics across individual complex pixel values, said enrollment manager performing said symmetrical reduction
15 procedure on said FFT reference image to produce a reduced reference image to conserve processing requirements and memory requirements, said FFT reference image being divided during said symmetrical reduction procedure into a reduced portion that is stored as said reference template, and a discarded portion that is not utilized during said pattern matching procedure.

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27. The method of claim 21 wherein said verification manager creates said correlation image by performing a multiplication procedure that multiplies corresponding pixel values from said reference template and said transformed test image to produce correlation pixel values for said correlation image, said
25 correlation pixel values being obtained from a multiplication lookup table to conserve system resources such as processing requirements and memory requirements.

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28. The method of claim 27 wherein said multiplication lookup table is implemented with initial binarization values from said binarization procedure, each complex value from said reference template and said transformed test image being expressed with one of only four complex numbers, said four complex numbers being " $1 + j$ ", " $1 - j$ ", " $-1 + j$ ", and " $-1 - j$ ", said multiplication lookup table including a vertical reference-pixel index column having a first reference pixel value ($1 + j$), a second reference pixel value ($1 - j$), a third reference pixel value ($-1 + j$), and a fourth reference pixel value ($-1 - j$), said multiplication lookup table also including a horizontal test-pixel index row having a first test pixel value ($1 + j$), a second test pixel value ($1 - j$), a third test pixel value ($-1 + j$), and a fourth test pixel value ($-1 - j$).

29. The method of claim 21 wherein said enrollment manager converts said initial reference image into an FFT reference image by performing a Fast Fourier Transform procedure upon said initial reference image.

30. The method of claim 29 wherein said enrollment manager performs a two-step binarization procedure upon said FFT reference image to produce a binarized reference image that is stored with a single binary bit representing each complex pixel value coefficient.

31. The method of claim 21 wherein said enrollment manager performs a symmetrical reduction procedure upon said binarized reference image to produce a reduced reference image which said enrollment manager stores as said reference template.

32. The method of claim 21 wherein said verification manager converts said initial test image into an FFT test image by performing a Fast Fourier Transform procedure upon said initial test image.

33. The method of claim 32 wherein said verification manager performs a two-step binarization procedure upon said FFT test image to produce a binarized test image that is stored with a single binary bit representing each complex pixel value coefficient.

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34. The method of claim 33 wherein said verification manager performs a symmetrical reduction procedure upon said FFT test image to produce and store a reduced test image.

10 35. The method of claim 34 wherein said verification manager performs a complex conjugation procedure upon said reference template to produce a conjugated reference image, said complex conjugation procedure converting each pixel value from said reference template into a corresponding complex conjugate value by inverting an arithmetic operation that connects real and
15 imaginary portions of complex values for said each pixel value from said reference template.

36. The method of claim 35 wherein said verification manager performs a multiplication procedure with said conjugated reference image and said
20 reduced test image to produce a reduced correlation image.

37. The method of claim 36 wherein said verification manager performs said multiplication procedure by referencing a multiplication lookup table to index pixel values from said conjugated reference image and said reduced
25 test image to produce corresponding correlation pixel values for said reduced correlation image.

38. The method of claim 36 wherein said verification manager performs a symmetrical regeneration procedure upon said reduced correlation image to
30 produce a full FFT correlation image.

39. The method of claim 38 wherein said verification manager performs an inverse FFT procedure upon said full FFT correlation image to generate a complex correlation image, said verification manager discarding imaginary values from each pixel value of said complex correlation image to produce a
5 real correlation image, said verification manager then performing an FFT shift procedure to generate a correlation graph that represents pixels from said real correlation image.

40. The method of claim 39 wherein said verification manager computes a
10 peak side-lobe ratio from said correlation graph for comparing with a pre-determined correlation threshold to determine whether said initial test image matches said initial reference image, said peak side-lobe ratio being expressed by a formula:

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$$\text{PSR} = (\text{Peak Value} - \text{Mean Value}) / \text{STD}$$

where said PSR is said peak side-lobe ratio, said Peak Value is a correlation image pixel with a greatest magnitude, said Mean Value is an arithmetical mean value of correlation image pixels in a pre-defined side-lobe area
20 surrounding said Peak Value, and said STD is a standard deviation of said correlation image pixels in said pre-defined side-lobe area.

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41. A computer-readable medium comprising program instructions for performing a pattern matching procedure by performing the steps of:
performing an image conversion procedure with an enrollment manager
to convert an initial reference image into a reference template,
5 said image conversion procedure including a binarization
procedure or a symmetrical reduction procedure;
converting an initial test image into a transformed test image with a
verification manager;
combining said reference template and said transformed test image into
10 a correlation image with said verification manager; and
analyzing matching characteristics of said correlation image with said
verification manager to determine whether said initial test image
matches said initial reference image.

15 42. A system for efficiently performing a pattern matching procedure,
comprising:
means for performing an image conversion procedure to convert an
initial reference image into a reference template, said image
conversion procedure including a binarization procedure or a
20 symmetrical reduction procedure;
means for converting an initial test image into a transformed test
image;
means for combining said reference template and said transformed test
image into a correlation image, and
25 means for analyzing matching characteristics of said correlation image
to determine whether said initial test image matches said initial
reference image.

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43. A system for efficiently performing a pattern matching procedure, comprising:

a electronic device that performs an image conversion procedure for converting an initial reference image into a reference template, said image conversion procedure including a binarization procedure; said electronic device analyzing matching characteristics of a test image and said reference template to determine whether said test image matches said reference template.

44. A system for efficiently performing a pattern matching procedure, comprising:

a electronic device that performs an image conversion procedure for converting an initial reference image into a reference template, said image conversion procedure including a symmetrical reduction procedure; said electronic device analyzing matching characteristics of a test image and said reference template to determine whether said test image matches said reference template.